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Climate change effect on the characteristics of raw domestic wastewater, sedimentation pond water, and treated wastewater

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ABSTRACT

The objective of this work was to investigate the effect of climate change on the characteristics of raw domestic wastewater, sedimentation pond water, and treated wastewater. The wastewater samples were collected from Khirbet Assamra wastewater treatment plant (KSWTP) in Azzarga Governorate in the Middle Region of Jordan. Descriptive statistics and inferential statistical tests were used for describtion and comparison purposes. Statistical analysis aimed at evaluating the ability of the sedimentation process to purify the water and assessing the overall wastewater treatment efficiciency of KSWTP. The results of the analysis showed that there are significant differences between the raw domestic wastewater, sedimentation pond water, and treated wastewater in pH ($F = 15.486$, $df = 149$, $p = .000$), the chemical oxygen demand ($F = 2486.459$, $df = 149$, $p = .000$), biochemical oxygen demand ($F = 2298.142$, $df = 149$, $p = .000$), ammonium ion concentration ($F = 4645.039$, $df = 149$, $p = .000$), total Kjeldahl nitrogen concentration ($F = 5908.067$, $df = 149$, $p = .000$), and the concentration of the total suspended solids ($F = 715{,}376$, $df = 149$, $p = .000$). When the characteristics of the raw domestic wastewater were compared with the characteristics of the treated wastewater, it was found that the wastewater treatment reduced the concentrations of total phosphorous and oil and grease and the counts of faecal coliform bacteria but had no significant effect on the mean water temperature and the concentration of dissolved phosphorous. It can be concluded that domestic wastewater treatment in KSWTP was to a large extent efficient in reducing the concentrations of total phosphorous and oil and grease and the counts of the faecal coliform bacteria in the treated wastewater. Further research is needed to compare levels of performance of other wastewater treatment methods with the method applied in KSWTP.

Keywords: Domestic waste water, Climate change, Sedimentation tanks.

تأثير تغير المناخ على خصائص مياه الصرف الصحي المنزلية الخام ومياه أحواض الترسيب ومياه الصرف الصحي المعالجة

أشرف عمر خشروم

قسم الانتاج النباتي/ التغير المناخي, سياسة الاستدامة والامن الغذائي

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الخلاصة

الهدف من هذا البحث هو دراسة تأثير التغير المناخي على خصائص مياه الصرف الصحي المنزلية الخام ومياه برك الترسيب ومياه الصرف الصحي المعالجة. تم جمع عينات مياه الصرف الصحي من محطة معالجة مياه الصرف الصحي في خربة السمرة في محافظة الزرقاء في المنطقة الوسطى من الأردن. تم استخدام الإحصاء الوصفي والاختبارات الإحصائية الاستدلالية لأغراض الوصف والمقارنة. هدف التحليل الإحصائي إلى تقييم قدرة عملية الترسيب على تنقية المياه وتقييم الكفاءة الشاملة لمعالجة مياه الصرف الصحي في محطة معالجة مياه الصرف الصحي في منطقة الدراسة. أظهرت نتائج التحليل أن هناك اختلافات كبيرة بين مياه الصرف الصحي المنزلية الخام ومياه بركة الترسيب ومياه الصرف الصحي المعالجة عند الرقم الهيدروجيني (F = 15.486، df = 149، p = .000)، ومتطلب الأوكسجين الكيميائي (F = 2486.459، df = 149، p = .000)، متطلب الأكسجين البيوكيميائي (F = 2298.142، df = 149، p = .000)، تركيز أيون الأمونيوم (F = 4645.039، df = 149، p = .000)، إجمالي تركيز النيتروجين (F = 5908.067، df = 149، p = .000)، وتركيز إجمالي المواد الصلبة العالقة (F = 715.376، df = 149، p = .000). عندما تمت مقارنة خصائص مياه الصرف الصحي المنزلية الخام مع خصائص مياه الصرف الصحي المعالجة، وجد أن معالجة مياه الصرف الصحي خفضت تركيزات الفوسفور الكلي والزيوت والشحوم وأعداد البكتيريا القولونية البرازية ولكن لم يكن لها تأثير كبير على المتوسطات في درجة حرارة الماء وتركيز الفوسفور المذاب. يمكن أن نستنتج أن معالجة مياه الصرف الصحي المنزلية في محطة معالجة مياه الصرف الصحي في منطقة الدراسة كانت فعالة إلى حد كبير في تقليل تركيزات الفوسفور الكلي والزيوت والشحوم وأعداد البكتيريا القولونية البرازية في مياه الصرف الصحي المعالجة. هناك حاجة إلى مزيد من البحث لمقارنة مستويات أداء طرق معالجة مياه الصرف الصحي الأخرى مع الطريقة المطبقة في البحث.

الكلمات الافتتاحية: مياه الصرف المنزلية, التغير المناخي, أحواض الترسيب.

INTRODUCTION

Rapid urbanization and the growing World population have led to the generation of substantial volumes of wastewater. Accordingly, treatment of wastewater has been advocated to curb water pollution and achieve water sustainability (Ho et al., 2021; Villa et al., 2020; Akash et al., 2020; Branchet et al., 2019; Riva et al., 2019; Sharma et al., 2019;). Water shortage and contamination is a problem worldwide, impacting the human health (Martínez-Oviedo et al., 2024). In developing countries, the rapid growth of the laundry industry in cities has led to environmental degradation, given its generation of substantial volumes of wastewater.” It was reported that, on the average, a laundry business uses 15 L of water to process 1 kg of clothing and discharges a total of 400 m3 of wastewater daily (Ho et al., 2021). Recently, it has emerged as a promising bioprocess for nutrient removal from various organic-deficient water and wastewater due to its specific advantages including high denitrification capacity, simultaneous nitrogen and phosphorus removal, self-buffering properties, and fewer by-product generation, e.g., sulphate, waste sludge, NO_2^-, NO_3^-, and NH_4^+ (Hu et al., 2020).

Water reform policies led to development of guidelines for recycled water, including stormwater, and augmentation of drinking water. Agricultural, industrial, and amenity-recycled water use was expanded (Radcliffe & Page, 2020). Most of the Arab countries, particularly Jordan, suffer from water scarcity as they receive only about 200 mm of rainfall annually. Therefore, many proposals were presented in order to manage the scarcity of water for different purposes, especially irrigation in the agriculture sector. Use of saline water, treated wastewater, and water from other sources have since long been suggested. However, these alternatives of fresh water require good management to succeed.

In line with the foregoing introduction, this study was conducted in Khirbet Assamra wastewater treatment plant (KSWTP) in Azzarga Governorate in the Middle Region of Jordan, where the weather is hot and dry during summer and very cold in winter. The objective of this work was to investigate the effect of wastewater treatment according to the stabilization pond method on the characteristics of sedimentation pond water and the treated wastewater.

METHODOLOGY

STUDY AREA AND SAMPLE COLLECTION

Water samples were taken from KSWTP dring the period of two months, extending from the beginning of September 2017 to the end of October 2017. With the exception of the oil and grease measurements, which were taken weekly, measurements of the rest of the variables were taken once every day. On this account, the number of readings for each water quality variable of interest ranged from 54 to 60.

CHEMICAL ANALYSIS

Wastewater samples were collected according to standard methods on a daily basis using special equipment and transferred in ice boxes to the lab for analysis. The samples included raw domestic wastewater (influent to KSWTP), sedimentation pond water, and treated wastewater. The water quality parameters of interest were temperature; pH; the chemical oxygen demand (COD); the biochemical oxygen demand (BOD); the total coliform bacteria count; and the concentrations of sulfide (S^{2-}), ammonium ion (NH_4^+), the total Kjeldahl nitrogen (TKN), the total suspended solids (TSS), the total volatile solids (TVS), dissolved phosphorous (PO_4^{3-}), total phosphorous (TP), and oil and grease.

STATISTICAL ANALYSIS

The water analysis data were analyzed using the Statistical Package for Social Sciences software, v. 22.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics and inferential statistical analysis were used to describe the water quality and compare the values of the investigated parameters between the three sampling points.

RESULTS AND DISCUSSION

The researcher computed a number of descriptive statistics for each wastewater sample and water quality variable under consideration, including the number of samples, the minimum value, the maximum value, range, arithmetic mean, and standard deviation. These results are presented in three sub-sections, the first of which relates to the raw (untreated) domestic wastewater while and the second and third pertain to the sedimentation ponds and the treatment plant effluent (treated wastewater), respectively.

Table 1 presents descriptive statistics for the water quality parameters of the raw wastewater during the study period (beginning of September 2017 to end of October 2017). With the exception of the concentration of oil and grease, which was measured once every week, measurements of the rest of the variables were taken daily. Hence, the number of measurements ranged for each variable from 54 to 60 (Table 1).

The results appearing in Table (1) indicate that the pH values were almost neutral; they had a range of values of less than 1.0 pH unit (0.62), corresponding to the minimum value of 6.81 and the maximum value of 7.43. The pH values had a mean of 7.22 and a standard deviation of 0.109. This standard deviation is low. It indicates that variations between the various raw wastewater samples in pH values were very low.

Temperature values of the raw wastewater samples varied from 24.60 °C to 28.90 °C (Table 1) and had a range of 4.30 °C. They had a mean of 26.82 °C and a standard deviation of 1.38 °C, which indicates that the temperature variations among the water samples collected over two months were low.

Table 1: Descriptive Statistics for the Raw Water [1]

Parameter	**Unit**	**N**	**Min.**	**Max.**	**Range**	**Mean**	**S.D**
pH	/	56	6.81	7.43	.62	7.22	.109
Temperature	°C	60	24.60	28.90	4.30	26.82	1.381
COD	mg/L	59	1076.0	1800.0	724.0	1289.03	146.343

BOD	mg/L	54	460	780	320.0	588.89	70.004
S^{2-}	mg/L	59	2.50	7.30	4.80	4.90	1.011
NH_4^+	mg/L	59	53.80	75.00	21.20	63.00	4.194
TKN	mg/L	59	89.60	114.80	25.20	101.54	5.542
TSS	mg/L	58	427.0	1240.0	813.0	601.50	128.962
TVS	mg/L	58	71.10	82.70	11.60	76.64	2.503
PO_4^{3-}	mg/L	59	4.78	8.60	3.82	6.72	.583
Total Phosphorous (TP)	mg/L	59	10.40	20.90	10.50	13.09	1.459
Oil and Grease	mg/L	8	31.80	73.20	41.40	53.44	15.776
Fecal Coliform Bacteria	CFU[2]	59	1,200,000	12,800,000	11,600,000	8,101,695	2,352,511

[1] N: Number of samples. Min.: Minimum value. Max.: Maximum value. S.D: Standard deviation
[2] CFU: Colony-forming unit

In the case of the chemical oxygen demand (COD), Table 1 reveals that the minimum and maximum CODs were 1076 mg/L and 1800 mg/L, respectively, corresponding to a COD range of 724 mg/L. The arithmetic mean COD concentration was about 1289 mg/L and the standard deviation was nearly 146.3 (Table 1). This standard deviation value is high. It indicates that there were some variations in the COD concentrations from one day to the next during the study period.

The biochemical oxygen demand (BOD) values were lower than the values of COD during the study period. They ranged from 460 mg/L to 780 mg/L (Table 1). As such, the range of BOD values was 320 mg/L (Table 1). Meanwhile, the mean BOD was approximately 588.9 mg/L. The results of the analysis (Table 1) additionally reveal high differences among the individual wastewater samples in BODs because the associated standard deviation was 70.0, which is relatively high.

The raw wastewater samples were characterized by low sulfide ion (S^{2-}) concentrations that ranged from 2.5 mg/L to 7.2 mg/L and had an arithmetic mean of about 4.9 mg/L (Table 1), which is a value that is close to the range of its concentrations (4.8 mg/L). As for the standard deviation of S^{2-} concentrations, it appears to be low (1.01 (Table 1)). But if we consider the low S^{2-} concentrations in these wastewater samples, then we infer from this standard deviation value that there are noteworthy differences amongst the individual raw wastewater samples in S^{2-} concentrations from day to day. That is, the concentrations of S^{2-} in the raw wastewater fluctuate daily.

Concentrations of ammonium ion (NH_4^+) in the raw wastewater samples ranged from 53.8 mg/L to 75.0 mg/L (Table 1), which means that the range of its concentrations was 21.2 mg/L. Meantime, its mean concentration was 63.0 mg/L. Furthermore, Table 1 demonstrates that the concentrations of this variable were characterized by a low standard deviation (4.19), indicating slight differences between the raw wastewater samples in concentration of NH_4^+.

The statistical analysis (Table 1) uncovered that the minimum and maximum total Kjeldahl nitrogen (TKN) concentrations in the raw wastewater samples were 89.6 and 114.8 mg/L, respectively, and that its range was 25.2 mg/L whereas its mean was almost 101.4 mg/L. The results (Table 1) also pinpoint limited variations between the individual samples in the TKN concentration, which means that the daily variations in concentrations of this variable were low.

The range of concentrations of the total suspended solids (TSS) in the studied samples was wide (813.0 mg/L (Table 1)); the TSS concentrations ranged during the two months of the study from 427.0 mg/L to 1240.0 mg/L. In the meantime, the mean TSS concentration was nearly 601.5 mg/L (Table 1). Based on this concentration range and the high standard deviation of concentrations (□ 129.0 mg/L), it can be concluded that there were substantial differences between the three types of wastewater in the TSS concentrations.

Concentrations of the total volatile solids (TVS) were generally low in the three water types. Their minimum value was 71.1 mg/L and their maximum value was 82.7 mg/L, corresponding to a range of 11.6 mg/L. The mean TVS concentration was nearly 76.6 mg/L (Table 1). This, and the value of the standard deviation, which was 2.5, indicate that the differences between the wastewater samples in TVS concentrations were low, which suggests that the concentrations did not change much from day to day during the two months of the study.

The dissolved phosphorous in the raw sewage, defined in terms of the phosphate ion (PO_4^{3-}), was characterized by low concentrations, ranging from 4.78 mg/L to 8.60 mg/L, with a range of 3.82 mg/L (Table 1). The concomitant mean and standard deviation values were 6.72 mg/L and 0.583, respectively. This somewhat low standard deviation value points to small daily variations in PO_4^{3-} concentrations in the wastewater.

The total phosphorous (TP) concentrations in the wastewater samples were also low; the lowest concentration was 10.4 mg/L while the highest concentration was 20.9 mg/L (Table 1). Accordingly, the range of TP concentrations was 10.5 mg/L. The mean TP concentration was approximately 13.09 mg/L and the standard deviation was almost 1.46, which uncovers that there were pronounced differences in TP concentrations from day to day during the two-month study period.

Regarding oil and grease, their concentrations in the raw wastewater samples ranged from 31.8 mg/L to 73.2 mg/L, and, therefore, the range of these concentrations was high (41.4 mg/L (Table 1)). While the arithmetic mean of oil and grease concentrations was 53.44 mg/L, the standard deviation was 15.78, which is a very high standard deviation, indicating that the concentrations of oil and grease varied greatly from day to day during the study period.

Counts of the fecal coliform bacteria (FCB) in the wastewater samples, expressed in colony-forming unit (CFU), were very high during the study period and fell in the range of 1,200,000-12,800,000 CFU, which is a wide range. Consequently, the mean of the counts of these bacteria is also high (8,101,695 CFU (Table 1)). It is inferred from these very high bacteria counts that the studied household wastewater is highly polluted with fecal bacteria. In other respects, the very high standard deviation (2,352,511 (Table 1)) indicates large variations in the counts of these bacteria in domestic wastewater from day to day.

Table 2 summarizes the values of descriptive statistics for water quality variables in the wastewater sedimentation ponds, i.e., the primary treatment ponds in KSWTP, which apply physical treatment of the wastewater based on deposition of precipitable solids from the water. At this stage of treatment, the researcher focused on seven water quality indicators: pH, COD, BOD, NH_4^+, TKN, TSS, and TVS (Table 2).

As can be seen in Table 2, the pH values were close to neutral. They varied within a narrow range of 0.8 pH units from 6.75 to 7.55. The associated mean pH and standard deviation were 7.13 and 0.165, respectively. This very low standard deviation value indicates that differences in the pH values between the sedimentation pond wastewater samples were low during the study period.

It is noticed in Table 2 that the minimum COD in the sedimentation ponds was 537 mg/L and that its maximum value was 774 mg/L, corresponding to a range of 237 mg/L. The mean COD was nearly 623 mg/L and the standard deviation was about 48.2 mg/L. The value of the standard deviation pinpoints noticeable variation in the COD during the study period from one day to another.

Table 2: Descriptive Statistics for the Sedimentation Pond Water [1]

Parameter	Unit	N	Min.	Max.	Range	Mean	S.D
pH	/	56	6.75	7.6	0.80	7.13	0.165
COD	mg/L	59	537.0	774.0	237.0	623.07	48.221
BOD	mg/L	54	300	380	80	328.15	23.154
NH_4^+	mg/L	59	54.9	75.0	20.10	61.83	3.934
TKN	mg/L	59	70.0	98.0	28.00	84.87	5.408
TSS	mg/L	58	84.0	392.0	308.0	184.43	51.090
TVS	mg/L	58	75.5	92.9	17.4	83.34	3.517

[1] N: Number of samples. Min.: Minimum value. Max.: Maximum value. S.D: Standard deviation

The BOD values were lower in the stabilization pond wastewater than the COD values. They varied from a minimum of 300 mg/L to a maximum of 380 mg/L. Accordingly, the COD range was 80 mg/L. However, the mean BOD was 328 mg/L. Moreover, the results of statistical analysis (Table 2) show that there were noteworthy differences between the individual wastewater samples in the BOD from a day to another as the standard deviation of the BOS\D measurements was 23.15.

Concentrations of NH_4^+ in the sedimentation pond wastewater ranged during the two-month study period from 54.9 mg/L to 75.0 mg/L. Hence, the range of NH_4^+ concentrations was 20.1 mg/L (Table 2). The mean and standard deviation of the NH_4^+ concentrations were 6.183 mg/L and 3.93, respectively. This somewhat low standard deviation uncovers slight differences between the sedimentation pond wastewater samples in NH_4^+ concentration from day to day during the study period.

Statistical analysis (Table 2) disclosed that the Total Kjeldahl Nitrogen (TKN) concentrations in the sedimentation pond wastewater samples had a range of 28 mg/L, corresponding to the minimum and maximum concentrations of 70 mg/L and 98 mg/L, respectively. The mean TKN concentration was about 84.87 mg/L (Table 2). Further, Table 2 unveils low variability among the individual wastewater samples in the TKN concentration because the standard deviation was low (~ 5.41). this implies that the daily variations among the samples in the TKN concentration were low.

With respect to the TSS, this study found that the range of their concentrations in the study samples was wide (308.0 mg/L (Table 2)). The concentrations varied during the two study months from 84.0 mg/L to 392.0 mg/L. Additionally, the mean TSS concentration was 184.4 mg/L while the standard deviation was 51.1. These high range and standard deviation values lead to the conclusion that there were pronounced differences in the TSS concentrations in the sedimentation ponds from one day to another.

The TVS concentrations were in general low. The minimum detected concentration was 75.5 mg/L whereas the maximum concentration was 92.9 mg/L (Table 2), which establish a range of concentrations of 17.4 mg/L. In addition, the mean TVS concentration was 83.33 mg/L. Further, concentrations of this variable had a low standard deviation (3.52 (Table 2)), which points out that the differences between the sedimentation pond wastewater samples in TVS concentration were low, that is, the concentrations did not differ much from a day to another during the study period.

Statistical analysis (Table 3) shows that the pH values of the treated wastewater were neutral; they had a very narrow range of 0.31, corresponding to minimum and maximum pH values of 6.99 and 7.30, respectively. The mean pH value was 7.09 and the standard deviation was about 0.086. This low standard deviation indicates that the differences between the treated wastewater samples in pH were very low.

Temperature values for the treated wastewater varied from 7.09 °C to 29.70 °C (Table 3), thus complying to a range of 27.32 (Table 3). If we consider the minimum value (7.09) as an extreme value (outlier) that might have resulted from a human measurement or reporting error, then the minimum temperature will be 25.50 °C, which is a reasonable value, and, therefore, the range of temperatures will be 4.20 °C, the mean temperature will be 27.66 °C, and the standard deviation will be 1.45, which is a low standard deviation that points to low variations among the treated wastewater samples in their temperatures during the study period.

In the case of the dissolved oxygen (DO), Table 3 spotlights that its minimum concentration was 5.04 mg/L while its maximal concentration was 7.10 mg/L, thus defining a range of 1.70 mg/L. In the meantime, the average DO concentration was about 6.81 mg/L whilst the standard deviation was nearly 0.317. This standard deviation is not much high. It reveals little variation in DO concentrations in KSWTP effluents from day to day during the study period.

Table 3: Descriptive Statistics for the Treated Wastewater [1]

Parameter	**Unit**	**N**	**Min.**	**Max.**	**Range**	**Mean**	**S.D**
pH	/	56	6.99	7.30	.31	7.091	.0858
Temperature	°C	60	7.09	29.70	22.61	27.32	3.021
DO	mg/L	60	5.40	7.10	1.70	6.810	.3170
COD	mg/L	59	35.6	54.1	18.5	41.76	3.624
BOD	mg/L	54	2.00	8	6	4.260	1.403
NO_3^-	mg/L	59	4.93	13.24	8.31	9.026	2.235
NO_2^-	mg/L	59	.070	.245	.175	.1060	.0516
NH_4^+	mg/L	59	.900	9.50	8.60	3.173	2.146

TKN	mg/L	59	4.00	13.40	9.40	6.276	2.283
Total nitrogen (TN)	mg/L	59	11.59	26.784	15.19	15.41	2.390
TSS	mg/L	58	2.20	14.8	12.6	6.486	2.185
TDS	mg/L	8	938	1032	94	989.8	32.05
Turbidity	NTU	60	1.40	9.50	8.10	4.113	1.664
PO_4^{3-}	mg/L	56	6.99	7.30	.31	7.091	.0858
TP	mg/L	59	1.00	7.74	6.74	4.257	1.612
Free Cl_2	mg/L	60	.030	.88	.85	.1993	.1408
Total Cl_2	mg/L	60	.220	2.69	2.47	.8910	.4105
Oil and Grease	mg/L	60	7.00	7.0	.0	7.000	.0000
Fecal Coliform Bacteria	CFU²	59	1	53	52	16.92	12.90
Fecal Coliform Bacteria	MPN²	8	17	20	3	17.38	1.061
Nematode Eggs	Count	9	.02	.06	.04	.0444	.0133

Table 3 uncovers that the minimum COD was 35.6 mg/L and that the maximal COD was 54.1 mg/L. The range of COD, hence, was 19.5 mg/L whereas the mean COD was around 41.76 mg/L and the standard deviation was approximately 3.62 mg/L. This standard deviation value underlines variations among the KSWTP effluents in COD during the study period, which may be attributed to quality of the influent wastewater and, presumably, the wastewater incubation period.

The BOD values ranged from a minimum of 2.0 mg/L to a maximum of 8.0 mg/L, thus defining a COD range of 6.0 mg/L (Table 3). The mean COD was approximately 4.26 mg/L. However, the COD measurements had a high standard deviation (1.40), which underlines that the differences between the treatment plant effluents in the BOD varied broadly from a day to another during the study period.

This study found that the minimum and maximum concentrations of NO_3^- in the treated wastewater were 4.93 mg/L and 13.24 mg/L, with a range of 8.31 mg/L and an average concentration of 9.03 mg/L (Table 3). The associated standard deviation was 2.23. This standard deviation value, which is almost half the minimum NO_3^- concentration, uncovers substantial differences in the concentration of NO_3^- between the water samples from one day to another during the study period.

Nitrite ion (NO_2^-) concentrations were very low in the treated wastewater, which is good. They varied from a minimum of 0.070 mg/L to a maximum of 0.245 mg/L, thus defining a range of 0.175 mg/L (Table 3). The mean NO_2^- concentration and the standard deviation were 0.106 mg/L and 0.052, respectively. This standard deviation is high once compared with the minimum and the mean NO_2^- concentrations, which suggests that there were very high differences in NO_2^- concentration between the treated wastewater samples during the two-month study period. It is also noticed that the NO_2^- concentrations exhibited higher fluctuations during the study period than any other water quality parameter under investigation.

Ammonium ion (NH_4^+) concentrations varied in the treatment plant effluents from 0.90 mg/L to 9.5 mg/L. Therefore, the range of NH_4^+ concentrations is 8.60 mg/L (Table 3). During the study period, the average NH_4^+ concentration was 3.17 mg/L and the standard deviation was 2.14. This standard deviation is high. It is indicative of high differences between the treated wastewater samples from one day to day in the NH_4^+ concentration.

Outcomes of statistical analysis (Table 3) disclosed that the minimum TKN concentration in KSWTP effluents was 4.00 mg/L, the maximum TKN concentration was 13.40 mg/L, and the range of TKN concentrations was 9.40 mg/L whilst the mean TKN concentration was approximately 6.28 mg/L and the concomitant standard deviation was 2.28. This very high standard deviation uncovers wide variations among the treated wastewater samples in TKN concentrations during the period of study (September to October 2017).

The total nitrogen (TN) concentration was one of the water quality variables studied by the researcher. As can be seen in Table 3, its minimum value was 11.59 mg/L while its maximum value was 26.78 mg/L. Their range of values is, thus 15.19 mg/L. The average TN concentration was 15.41 mg/L and the standard deviation was 2.39 (Table 3). This value of standard deviation is somewhat high. It suggests that there were profound daily differences between the treated wastewater samples in the TN concentration during the study period. This finding of high variations in TKN concentration during the study period accords with the findings relating to concentrations of NO_3^-, NO_2^-, NH_4^+, and TKN. They highlight that either the wastewater incubation period in KSWTP is inconsistent or that concentrations of nitrogen in the influent water are highly varying, or both.

The range of the TSS concentrations in the treated wastewater samples was wide (12.6 mg/L), but the concentrations were in general very low, varying during the two study months from 2.2 mg/L to 14.8 mg/L. The average TSS concentration in these samples was 6.486 mg/L. It is concluded from the range of TSS concentrations (12.6 mg/L) and the very high value of the standard deviation (~ 2.18) that pronounced differences existed in the TSS concentration between the treatment plant effluents during the period of this study.

The current study found that the minimum value of the TDS was 938 mg/L while its maximum value was 1032 mg/L. Moreover, the TDS concentrations had a range of 94.0 mg/L, a mean of 989.75 mg/L, and a standard deviation of 32.05 (Table 3). This is a very low standard deviation when it is compared with the minimum value and the mean. Based on the standard deviation value, it is inferred that the TDS concentration did not vary much from a day to another during the study period.

Turbidity was generally low in the treated wastewater samples. It ranged from 1.40 Nephleometric Turbidity Units (NTU) to 9.50 NTU, corresponding to a range of 8.10 NTU. Meantime, the average turbidity was about 4.11 NTU (Table 3). This low turbidity is consistent with the TSS concentrations in the treated wastewater samples, which too were low. However, despite the generally low turbidity in the treated wastewater samples, the value of the standard deviation is high (1.66), uncovering high variations among the water samples in turbidity during the study period.

The results of the statistical analysis (Table 3) show that the concentrations of PO_4^{3-} in the wastewater treatment plant effluents were low, ranging from 6.99 mg/L to 7.30 mg/L. The range of these concentrations is nearly 0.31 mg/L. Meanwhile, the mean PO_4^{3-} concentration and the standard deviation were, respectively, 7.09 mg/L and 0.0858 (Table 3). This low standard deviation leads to the conclusion that the daily differences in the PO_4^{3-} concentration between KSWTP effluents were very low during the study period.

Total phosphorus (TP) concentrations in the treated wastewater samples were also low. The lowest concentration was 1.00 mg/L whereas the highest concentration was 7.74 mg/L (Table 3). Accordingly, the range of its concentrations was 6.74 mg/L. However, the mean TP concentration during the two months of study was approximately 4.26 mg/L and the standard deviation was 1.61, which is very high. This standard deviation value reveals remarkable differences between the effluents in the concentration of TP from day to day.

Concentrations of free chlorine (free Cl_2) were very low in the treated wastewater samples. They ranged from 0.03 mg/L to 0.88 mg/L (Table 3). So, the range of free Cl_2 concentrations was nearly 0.85 mg/L. Meanwhile, the mean concentration and the standard deviation were almost 0.20 mg/L and 0.141, respectively. In comparison with the minimum concentration of free Cl_2 (0.03 mg/L) and the average concentration (0.20 mg / L), the present study finds that the standard deviation of the free Cl_2 concentrations during the study period is high. This unveils high variability in free Cl_2 concentration in the treated wastewater samples from one day to another during the study period.

The foregoing finding (the previous paragraph) applies to the total chlorine (Total Cl_2) concentration in KSWTP effluents, which lied in the range of 0.22−2.69 mg/L (Table 3). Its mean concentration was 0.891 mg/L and the standard deviation of its measurements was 0.410. Relative to the minimum and mean Total Cl_2 concentrations, this standard deviation is very high, suggesting broad daily variations among the treatment plant effluents in the Total Cl_2 concentration during the two-month study period.

The concentration of oil and grease in the treatment plant effluents was very nearly constant (7.0 mg/L) during the study period. So, the effluents had a mean concentration of 7.00 mg/L and zero range and standard deviation (Table 3). These results can be explained by the fact that oil and grease were measured in the different wastewater samples once a week, not daily.

Counts of the fecal coliform bacteria in the treated wastewater samples were low during the study period, ranging from 1 to 53 CFU and having a very narrow range (52 CFU). In view of this, the mean fecal coliform bacteria count too was low (16.92 CFU (Table 3)). However, the results of statistical analysis (Table 3) reveal noticeable differences between the treated wastewater samples in their fecal coliform bacteria content from a day to another as evidenced by the standard deviation of counts of these bacteria (12.90). These low bacteria counts lead to the conclusion that the water treatment method used in the study wastewater treatment plant is highly effective in disposing of the fecal coliform bacteria. However, when expressing the fecal coliform bacteria counts in terms of the most probable number (MPN), this study finds that the minimum fecal coliform bacteria count is 17 MPN and that the maximum count is 20. Consequently, the range of counts is 3 MPN. Moreover, the average count is 17.38 MPN. But contrary to the case when the FCB counts are expressed in the unit of CFU, Table 3 unveils that the daily differences between the treated wastewater samples in their fecal coliform bacteria content are not much high since the associated standard deviation is around 1.06 (Table 3), which is low.

Lastly, the nematode eggs were generally low in the treatment plant effluents during the study period. Their minimum count was 0.02 whereas their maximum count was 0.06 and their mean count was 0.04 (Table 3). It should be highlighted that the standard deviation of the nematode egg counts was very low in the treated wastewater samples (0.0133). Nevertheless, contrasting this value (0.0133) with the minimum and mean nematode egg counts uncloses noteworthy differences between the treated wastewater samples in their nematode egg content from one day to another during the study period, which can be ascribed to daily variations in the nematode egg content of the influent domestic wastewater.

After identifying the characteristics of the raw domestic wastewater, the sedimentation pond water, and the treated wastewater, a statistical comparison between these three water types in their characteristics was made with the aim of identifying the ability of the sedimentation process to purify the water and the ability of subsequent treatment to treat the wastewater. There were six variables common to the wastewater samples in the three phases (Table 4): pH, BOD, COD, NH_4^+ concentration, TKN, and TSS. The group mean comparisons were made using one-way analysis of variance (ANOVA) and version 24.0 of the SPSS software at the level of significance of 0.05 (α = .05). In all group mean comparisons, the null hypothesis states that there is no statistically-significant difference between the groups under comparison while the research (alternative) hypothesis states that there are statistically-significant differences. The null hypothesis is rejected and the alternative hypothesis is accepted if the probability value (p) is less than α = 0.05.

The results of ANOVA presented in Table 4 show that there are significant differences between the raw domestic wastewater, sedimentation pond water, and treated wastewater in each of pH (F = 15.486, df = 149, p = .000), the COD (F = 2486.459, df = 149, p = .000), the BOD (F = 2298.142, df = 149, p = .000), concentration of NH_4^+ (F = 4645.039, df = 149, p = .000), concentration of TKN (F = 5908.067, df = 149, p = .000), and concentration of TSS (F = 715,376, df = 149, p = .000). However. though ANOVA proved that there are statistically-significant differences between the three wastewater types in their characteristics, it did not define the similar and different groups in the case of each studied water quality variable. In consequence, the researcher conducted Tukey's HSD *post hoc* test to identify the similar and different groups. This test too was carried out at α of 0.05. The main results of this test are presented in a number of tables in the following paragraphs.

Table 4: Analysis of Variance (ANOVA) to Test for Significant Differences in Characteristics of the Three Wastewater Types

Parameter	**Unit**		**SS**	***df***	**MSS**	***F***	***p***
pH	/	Between Groups	.454	2	.227	15.486	.000
		Within Groups	2.153	147	.015		
		Total	2.607	149			
COD	mg/L	Between Groups	40287273.080	2	4338744.807		.000
		Within Groups	1190896.160	147	1887.936		
		Total	41478169.240	149			
BOD	mg/L	Between Groups	8677489.613	2	4338744.807	2298.142	.000
		Within Groups	277526.580	147	1887.936		
		Total	8955016.193	149			
NH_4^+	mg/L	Between Groups	116372.167	2	58186.084	4645.039	.000
		Within Groups	1841.395	147	12.526		

		Total	118213.563	149			
TKN	mg/L	Between Groups	258917.423	2	129458.711	4645.039	.000
		Within Groups	3221.092	147	21.912		
		Total	262138.515	149			
TSS	mg/L	Between Groups	9791972.853	2	4895986.427	715.376	.000
		Within Groups	1006058.640	147	6843.936		
		Total	10798031.490	149			

The results of Tukey's HSD *post hoc* test presented in Table 5 and Table 6 spotlight that there was no statistically-significant difference between the mean pH values of the treated wastewater and the sedimentation pond water (mean pH $\simeq$ 7.10) whereas the average pH of the raw wastewater (~ 7.21) was higher than the mean pH values of the raw wastewater and the sedimentation pond water. This means that the sedimentation ponds and the subsequent treatment reduce the pH values of the wastewater. It is possible, based on the results listed in Table 5, to say that wastewater treatment in KSWTP reduces the pH values slightly while the sedimentation ponds do not.

Table 5: Tukey's *post hoc* Test of Similar Groups: pH [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	*p*
pH	/	Raw Wastewater	Sedimentation Pond Water	.0976*	.000
			Treated Wastewater	.1292*	.000
		Sedimentation Pond Water	Raw Wastewater	−.0976*	.000
			Treated Wastewater	.0316	.394
		Treated Wastewater	Raw Wastewater	−.1292*	.000
			Sedimentation Pond Water	−.0316	.394

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)

Table 6: Tukey's *post hoc* Test of Similar and Different Groups: All Water Quality Parameters [1]

Parameter	Unit		Group 1	Group 2	Group 3
pH	/	Treated Wastewater	7.078		
		Sedimentation Pond Water	7.109		
		Raw Wastewater		7.2070	
COD	mg/L	Treated Wastewater	41.186		
		Sedimentation Pond Water		619.380	
		Raw Wastewater			1309.000
BOD	mg/L	Treated Wastewater	4.220		
		Sedimentation Pond Water		327.60	
		Raw Wastewater			1309.000
NH_4^+	mg/L	Treated Wastewater	2.886		
		Sedimentation Pond Water		61.452	
		Raw Wastewater		62.478	
TKN	mg/L	Treated Wastewater	5.964		
		Sedimentation Pond Water		84.410	
		Raw Wastewater			101.332
TSS	mg/L	Treated Wastewater	6.240		
		Sedimentation Pond Water		186.680	
		Raw Wastewater			615.440

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)

Tukey's *post hoc* test (Table 7) indicates that there are significant differences in the mean COD among the three wastewater types. Table 6 points out that the average COD was higher in the raw wastewater (1309 mg/L) than in the sedimentation pond water (619 mg/L) and in the treated wastewater (41.186 mg/L). Accordingly, it is inferred that the sedimentation ponds reduce the COD of the wastewater and that the final treatment reduces it further.

Table 7: Tukey's *post hoc* Test to Identify Similar Groups: COD [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	p
COD	mg/L	Raw Wastewater	Sedimentation Pond Water	689.620*	.000
			Treated Wastewater	1267.814*	.000
		Sedimentation Pond Water	Raw Wastewater	-689.620*	.000
			Treated Wastewater	578.194*	.000
		Treated Wastewater	Raw Wastewater	-1267.814*	.000
			Sedimentation Pond Water	-578.194*	.000

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)
* Differences between means are significant at α = .05

The BOD status is somewhat similar to that of the COD. Table 8 shows that there are statistically-significant differences in the mean BOD of the three wastewater types. In line with this, Table 6 uncovers that the sedimentation ponds reduced the mean BOD to about half of its concentration in the raw wastewater (529.40 mg/L to 327.60 mg/L) while the final treatment reduced the mean BOD greatly from 327.60 mg/L to 4.22 mg/L. It is concluded, accordingly, that the wastewater treatment in KSWTP is very efficient in reducing the COD and BOD of the wastewater.

Table 8: Tukey's *post hoc* Test to Identify Similar Groups: BOD [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	p
BOD	mg/L	Raw Wastewater	Sedimentation Pond Water	264.800*	.000
			Treated Wastewater	588.180*	.000
		Sedimentation Pond Water	Raw Wastewater	-264.800*	.000
			Treated Wastewater	323.380*	.000
		Treated Wastewater	Raw Wastewater	-588.180*	.000
			Sedimentation Pond Water	-323.380*	.000

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)
* Differences between means are significant at α = .05

Tukey's *post hoc* test (Table 9) uncloses that there is no statistically-significant difference in the mean NH_4^+ concentration between the sedimentation pond water and the raw wastewater (p = .318), which means that the sedimentation ponds do not significantly reduce the concentration of this ion. However, Table 9 and Table 6 reveal that the average concentration of this ion was significantly (p = .000) lower in the treatment plant effluent (2.88 mg/L) than in the raw wastewater (62.48 mg/L) and in the sedimentation pond water (61.45 mg/L). This supports high ability of wastewater treatment at KSWTP to significantly reduce NH_4^+ concentration.

Table 9: Tukey's *post hoc* Test to Identify Similar Groups: NH_4^+ [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	p
NH_4^+	mg/L	Raw Wastewater	Sedimentation Pond Water	1.026	.318
			Treated Wastewater	59.592*	.000
		Sedimentation Pond Water	Raw Wastewater	-1.026	.318
			Treated Wastewater	58.566*	.000
		Treated Wastewater	Raw Wastewater	-59.592*	.000
			Sedimentation Pond Water	-58.566*	.000

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)
* Differences between means are significant at α = .05

The results of statistical testing (Table 10) unveil that there are significant differences in the mean TKN concentration amongst the three wastewater types. In this context, Table 6 shows that the sedimentation ponds reduced the mean TKN concentration from 101.3 mg/L to 84.4 mg/L and that the final treatment reduced it substantially from 84.4 mg/L to 5.96 mg/L. These results lead to the conclusion that the wastewater treatment method applied in KSWTP, which is the stabilization pond method, is highly efficient in reducing TKN concentrations in the wastewater.

Table 10: Tukey's *post hoc* Test to Identify Similar Groups: TKN [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	*p*
TKN	mg/L	Raw Wastewater	Sedimentation Pond Water	16.9220*	.000
			Treated Wastewater	95.3676*	.000
		Sedimentation Pond Water	Raw Wastewater	-16.9220*	.000
			Treated Wastewater	78.4456*	.000
		Treated Wastewater	Raw Wastewater	-95.3676*	.000
			Sedimentation Pond Water	-78.4456*	.000

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)
[*] Differences between means are significant at α = .05

Outputs of Tukey's *post hoc* test (Table 11) bring to notice that there are significant differences in the mean TSS concentrations between the wastewater samples of the three types. Based on the results listed in Table 6, this study found that that the sedimentation ponds reduce the TSS concentration considerably and that the final treatment lowers it even more. Table 6 uncloses that the average concentration of the TSS was higher in the raw wastewater (615.4 mg/L) than in the sedimentation pond water (186.7 mg/L) and in the treated wastewater, which had the lowest mean TSS concentration (6.24 mg/L). On account of this, the researcher concludes that the domestic wastewater treatment method used in KSWTP is characterized by very high efficiency in removal of the TSS.

Table 11: Tukey's *post hoc* Test to Identify Similar Groups: TSS [1]

Parameter	Unit	Group 1	Group 2	Mean Difference	*p*
TSS	mg/L	Raw Wastewater	Sedimentation Pond Water	428.760*	.000
			Treated Wastewater	609.200*	.000
		Sedimentation Pond Water	Raw Wastewater	-428.760*	.000
			Treated Wastewater	180.400*	.000
		Treated Wastewater	Raw Wastewater	-609.200*	.000
			Sedimentation Pond Water	-180.440*	.000

[1] Level of statistical significance (α) is 0.05. Numbers of samples are equal (N = 50)
[*] Differences between means are significant at α = .05

The various studied water quality variables included five variables that were common to the raw domestic wastewater and the treated wastewater (Table 12): temperature (°C), concentration of PO_4^{3-} (mg/L), concentration of TP (mg/L), concentration of oil and grease (mg/L), and count of fecal coliform bacteria (CFU). To examine the differences between these two types of wastewater in the mean values of these five variables, the researcher performed group mean comparisons using the two, independent-sample t test at α of 0.05. Table 12 presents the outputs of this test. It discloses that domestic wastewater treatment at KSWTP reduced the concentrations of TP and oil and grease and the counts of the fecal coliform bacteria significantly, but did not significantly affect the mean water temperature and the PO_4^{3-} concentration.

Table 12: Two, Independent-Sample *t* Test of Differences in Water Quality Characteristics

Parameter	Water Type	Mean	*df*	*t*	*p*
Temperature (°C)	Raw Wastewater	26.9750	60	-.404	.502
	Treated Wastewater	27.4350			
PO_4^{3-} (mg/L)	Raw Wastewater	6.7838	60	-2.723	.335
	Treated Wastewater	7.0893			
TP (mg/L)	Raw Wastewater	13.7500	60	13.452	.000*
	Treated Wastewater	4.3163			
Oil and Grease (mg/L)	Raw Wastewater	53.438	60	22.748	.000*
	Treated Wastewater	7.000			
Fecal Coliform Bacteria (CFU)	Raw Wastewater	8800000	60	32.983	.000*
	Treated Wastewater	17			

The results of the *t* test (Table (12) bring to notice that there was no statistically-significant difference in the mean temperature between the raw and the treated wastewater during the study period ($t = -.404$, $df = 60$, $p = .502$), which means that domestic wastewater treatment in KSWTP does not have a statistically significant effect on water temperature.

The *t* test results (Table 12) show that there was no statistically-significant difference in the concentration of dissolved phosphorous (PO_4^{3-}) between the treated wastewater and the raw wastewater ($t = -.2.723$, $df = 60$, $p = .335$). In this respect, the mean PO_4^{3-} concentration was 6.78 mg/L in the treated wastewater and 7.09 mg/L in the raw wastewater, which are very close.

Table 12 highlights a statistically-significant difference in the mean TP concentration during the study period between the raw and the treated wastewater ($t = 13.452$, $df = 60$, $p = .000$). The mean TP concentration was 13.75 mg/L in the raw wastewater and 4.32 mg/L in the treated wastewater. This indicates that water treatment in KSWTP reduces the TP concentration to less than a third of its initial concentration.

It is seen in Table 12 that a statistically-significant difference in the mean oil and grease concentration existed between the raw and the treated wastewater in the study period ($t = 22.748$, $df = 60$, $p = .000$). The results (Table 12) spotlight that the mean oil and grease concentration was 53.44 mg/L in the raw wastewater and 7.00 mg/L in the treated wastewater. This finding confirms the high capability of the water treatment system used in KSWTP to significantly reduce the oil and grease concentrations in the wastewater.

The *t* test results (Table 12) reveal a statistically-significant difference in the mean fecal coliform bacteria counts, expressed in CFU, between the treated wastewater and the raw wastewater ($t = 32.983$, $df = 60$, $p = .335$). The arithmetic mean of the fecal coliform bacteria counts was 17 CFU in the treated wastewater and 8,800,000 CFU in the raw wastewater. This difference corresponds to a huge reduction in the counts of these bacteria in the wastewater.

In brief, and based on the *t* test results (Table 12), the researcher concludes that wastewater treatment in KSWTP succeeded to a large extent in reducing the concentrations of TP and oil and grease and the counts of the fecal coliform bacteria in the wastewater to a high extent.

CONCLUSIONS AND RECOMMENDATIONS

The goal of this study was to assess the characteristics of raw domestic wastewater, sedimentation basin water, and treated wastewater in KSWTP in Azzarga Governorate in the Middle Region of Jordan and to evaluate the wastewater treatment efficiency. The study results disclosed few differences between the water samples in the concentrations of the investigated parameters from day to day during the study period (beginning of September 2017 to end of October 2017). The results also showed that wastewater treatment in KSWTP lowers the wastewater pH values slightly. In addition, it was found that that the wastewater treatment method employed in KSWTP is very efficient in reducing the COD and BOD; the concentrations of NH_4^+, TKN, total phosphorous, and oil and grease; and the counts of the faecal coliform bacteria. However, the treatment method employed in KSWTP had no significant impact on water temperature or the concentration of dissolved phosphorus (PO_4^{3-}). Further research is needed to compare levels of performance of other wastewater treatment methods with the method applied in KSWTP.

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